

## RESEARCH ARTICLE

## PHOSPHORUS AVAILABILITY IN MINERAL ACID SOILS IMPROVES USING SOIL ORGANIC CONDITIONER PRODUCED FROM CHICKEN DUNG

Siti Hadiyah Azlan<sup>a\*</sup>, Osumanu Haruna Ahmed<sup>a\*</sup>, Rose Abdullah<sup>a</sup>, Nur Thaqifah Salihah<sup>a</sup>, Syahirah Shahlehi<sup>a</sup>, Kathereen Liew<sup>b</sup>, Mohamed Mujithaba Mohamed Najim<sup>a</sup>, Hassan Ammouneh<sup>a</sup>, and Siti Nur Idayu Matusin<sup>c</sup>

<sup>a</sup> Faculty of Agriculture, Universiti Islam Sultan Sharif Ali (UNISSA), Sinaut Campus, Brunei Darussalam

<sup>b</sup> Unit of Soil Science and Plant Nutrient, Department of Agriculture and Agrifood

<sup>c</sup> Faculty of Halal Science and Sustainable Tourism, UNISSA, Sinaut Campus, Brunei Darussalam

\*Corresponding Author Email: [hadiyah.azlan16@gmail.com](mailto:hadiyah.azlan16@gmail.com), [ahmed.haruna@unissa.edu.bn](mailto:ahmed.haruna@unissa.edu.bn)

This is an open access article distributed under the Creative Commons Attribution License CC BY 4.0, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

## ARTICLE DETAILS

## Article History:

Received 26 January 2026  
Revised 20 February 2026  
Accepted 25 February 2026  
Available online 05 March 2026

## ABSTRACT

Brunei Darussalam has long faced challenges associated with low-pH soils, which contribute to low crop productivity. These highly weathered soils are characterized by low nutrient availability and high concentrations of aluminium (Al) and iron (Fe), which strongly bind phosphorus (P) through chelation thus rendering it unavailable to plants. Although the application of inorganic P fertilizers partially alleviates P deficiency, substantial losses occur through leaching, fixation, and immobilization. The use of an organic soil conditioner (OSC) derived from chicken manure represents a practical and sustainable approach for improving soil P availability. An incubation study was conducted to evaluate changes in soil available P and selected soil chemical properties. The experiment was arranged in a Completely Randomized Design (CRD) with five treatments: T1 (0% OSC), T2 (100% OSC), T3 (75% OSC), T4 (50% OSC), and T5 (25% OSC), each with three replicates over a 30-day incubation. The application of OSC increased soil pH and electrical conductivity (EC). Moreover, this approach significantly reduced the soil exchangeable acidity,  $Al^{3+}$ , and  $H^+$  through dissolution and neutralization reactions involving organic anions. Consequently there was an increment of 402.41 - 1154.85 ppm available P with the treated soil compared with the control (T1). In addition, the increase in soil organic carbon and organic matter enhanced P availability by promoting nutrient cycling and reducing P fixation. These findings demonstrate that OSC effectively ameliorates soil acidity and enhances P availability, indicating its potential to improve crop productivity on mineral acid soils.

## KEYWORDS

available P, low-pH soil, soil conditioners, soil remediation, poultry wastes

## 1. INTRODUCTION

Soil fertility and nutrient availability are fundamental determinants of agricultural productivity, particularly in regions with tropical and subtropical climates where acidic soils are prevalent (FAO and ITPS, 2015). Acidic soils, such as Ultisols and Oxisols, are characterized by low pH, high concentrations of  $Al^{3+}$  and  $Fe^{3+}$  oxides, and limited cation exchange capacity (CEC), leading to base cations deficiency such as K, Mg, and Ca (Osman, 2018b). These chemical properties significantly affect the availability of essential nutrients, particularly P, which is an important macronutrient for plant growth and development. Phosphorus plays an essential role in several physiological and biochemical processes in plants, including energy transfer through adenosine triphosphate (ATP), nucleic acid synthesis, membrane formation, and root development (Malhotra et al., 2018; Weil and Brady, 2016). Despite its critical importance, P deficiency is a common limitation in acidic soils due to its strong fixation by Fe and Al compounds, a chemical reaction which renders it largely unavailable for plant uptake (Osman, 2018a; Shen et al., 2011). This causes a major constraint to achieving optimal crop productivity, necessitating targeted interventions to enhance P availability in these soils.

Soil chemical properties and management practices influence P dynamics in acid soils. In highly weathered soils, the predominant forms of P are often associated with Fe and Al oxides. Under low pH conditions, phosphate ions ( $PO_4^{3-}$ ) readily react with  $Al^{3+}$  and  $Fe^{3+}$  to form insoluble

complexes, thus reducing the plant-available P (Warke and Wakgari, 2024). Additionally, the low buffering capacity of mineral acid soils limits their ability to resist changes in pH, which further causes losses of P through leaching and surface runoff (Ng et al., 2024). As a result, conventional applications of inorganic P fertilizers in acid soils are often inefficient, causing the applied P to become immobilized and/or leached out shortly after application. This inefficiency not only increases production costs but it also poses environmental risks, including nutrient runoff and eutrophication of water bodies. Similarly, opined that application of chemical fertilisers to a soil with reduced buffering capacity causes further acidification and reduces buffering capacity, slow biological activity, and deplete the organic matter (Dvořáčková et al., 2022). Therefore, improving P availability in acid mineral soils is a serious challenge for sustainable agriculture and food security.

The use of organic soil conditioners in agriculture has been recognized as an effective strategy to improve soil fertility and nutrient availability in acid soils. Among these, composted chicken dung has emerged as a promising organic amendment because of its high nutrient content, organic matter composition, and beneficial effects on soil physical, chemical, and biological properties. Chicken dung contains significant quantities of nitrogen (N), P, potassium (K), and organic carbon, making it an ideal source of nutrients for crop production (Chen et al., 2023; Thepsilvisut et al., 2022; Dikinya and Mufwanzala, 2010). Also, chicken dung improves soil structure, increases water-holding capacity, and

## Quick Response Code



## Access this article online

Website:  
[www.mjsa.com.my](http://www.mjsa.com.my)

DOI:  
10.26480/mjsa.01.2026.53.61

enhances microbial activity, which supports nutrient cycling and availability (Agbede, 2025; Islam et al., 2021; Maikol et al., 2021). When applied to acid soils, chicken dung increases soil pH through its liming effect, retains available nutrients in the soils, reduces exchangeable Al toxicity, and promotes solubilization of previously fixed P, thereby enhancing plant-available P.

In summary, P deficiency in acidic soils is a major constraint to agricultural productivity, driven by low pH, strong P fixation by Fe and Al oxides, and P runoff. Organic soil conditioner produced from chicken dung offers a practical and sustainable approach to improving P availability. To this end, the objective of this study was to determine the effects of repurposing chicken dung into an organic soil conditioner on soil P availability in an acid soil. By analysing the P and examining associated changes in selected soil properties, the research looks to provide an understanding of how organic soil conditioner influence P dynamics. The findings are expected to suggest sustainable soil management strategies for improving P use efficiency, reducing reliance on inorganic fertilizers, and enhancing agricultural productivity in tropical acidic soils.

## 2. MATERIALS AND METHODS

### 2.1 Soil sampling, preparation, and organic soil conditioner production

The soil used for this study was collected from an uncultivated agricultural land at Universiti Islam Sultan Sharif Ali (UNISSA), Sinaut Campus. The collected soil was taken at a depth of 0-20 cm using an augur after which it was air-dried on a clean surface covered with a plastic sheet. Afterwards, the dried soil was ground using a pestle and mortar and sieved to pass a 2 mm sieve using a laboratory-grade soil sifter. The prepared soil was stored in plastic zip-lock bags, and therefrom, the soil analysed for selected chemical properties.

The organic soil conditioner (OSC) was produced using locally available raw materials. Dried chicken dung (DCD), chicken feed, and chicken dung slurry (CDS) were thoroughly mixed. The CDS was produced from combining fresh chicken dung (FCD), molasses, and water. The temperature of the OSC was taken twice, at 7 AM and 5 PM, every 48 hours. The co-composting process was carried out for 55 days to ensure that matured or quality OSC was produced. Thereafter, the finished product was sampled, air-dried, and analysed for selected chemical and physical properties.

### 2.2 Soil and organic soil conditioner characterisation

The soil pH and EC in water were determined following the procedures adopted by the Food and Agriculture Organisation (FAO) (2021b, 2021c). The soil suspension was prepared with a ratio of 1 g of soil: 10 mL of distilled water and was mixed using a reciprocal shaker set at 120 rpm for 15 minutes. The pH and EC of the soil-water mixture were determined using a digital pH and an EC meter, respectively. pH in KCl was also determined; a ratio of 1 g of soil: 2.5 mL of KCl solution was used to prepare the soil suspension and afterwards analysed for pH using a digital pH meter. The soil exchangeable acidity,  $\text{Al}^{3+}$ , and  $\text{H}^+$  were extracted using 1 M KCl and determined using acid-base titration (Rowell, 1994). The total organic carbon and organic matter of the soil were determined using a redox titration, the Walkley-Black method (Global Soil Laboratory Network and Nilo, 2019). Available P was extracted using the Melich-1 method, this was followed by the development of blue colour using the molybdenum blue method and measurement using a UV-Vis spectrophotometer (FAO, 2021a; Murphy and Riley, 1962). Available K and exchangeable Ca, Mg, and Na were extracted just as available P and determined using the Atomic Absorption spectrophotometer (AAS).

The physical and chemical characteristics of the OSC were determined. The colour of the organic amendment was determined using the Munsell Colour Chart to provide initial information on organic amendment maturity, and to compare the colour with those reported in the literature (Omar et al., 2021; Latifah et al., 2015; Ch'ng et al., 2013). The OSC pH and EC were determined in the same manner as soil pH in water and EC. Total P, K, Mg, Ca, and Na of the OSC were extracted using the aqua regia method ( $3 \text{ HCl} : 1 \text{ HNO}_3$ ) (Moursy et al., 2020). The molybdenum blue method was used to determine Total P. As for total K, Mg, Ca, and Na they were determined using the AAS.

### 2.3 Soil incubation study

An incubation experiment was set up for 30 days at the Ibnu Sina Scientific Laboratory Centre, Sinaut Campus, Universiti Islam Sultan Sharif Ali (UNISSA), Brunei following the procedure of Chong et al. (2022) with modifications. The modifications made in this experiment were: from the prepared 2 mm sieved soil, 200 g of the soil was weighed and prepared using a precision balance into a plastic container, and the process was

replicated three times. Application rate of the organic amendment used in the incubation study was based on  $5 \text{ t ha}^{-1}$  with the organic amendment varied by 0% (T1), 100% (T2), 75% (T3), 50% (T4), and 25% (T5). Amount of the organic soil conditioner (OSC) used was scaled down to a per-plant basis of 200 g of soil (Based on planting density of 27,777 plant  $\text{ha}^{-1}$ ), equivalent to 180 g of organic amendment. The rate was based on the standard maize (*Zea mays* L.) cultivation recommendation (Johan et al., 2021). The treatments evaluated were as follows:

- (i) T1: 200 g of soil only (0% of OSC)
- (ii) T2: 200 g soil + 180 g of organic soil conditioner (100% of OSC)
- (iii) T3: 200 g soil + 135 g of organic soil conditioner (75% of OSC)
- (iv) T4: 200 g soil + 90 g of organic soil conditioner (50% of OSC)
- (v) T5: 200 g soil + 45 g of organic soil conditioner (25% of OSC)

The soil and organic soil conditioner were mixed thoroughly, moistened to 60% moisture content based on field capacity, and incubated at room temperature ( $\sim 25^\circ\text{C}$ ). The containers with the treatments were closed lightly with the container lid to allow aeration. The experiment was arranged using a Complete Random Design (CRD). The total experimental units for the incubation study were 15 (Five treatments  $\times$  Three replicates). After 30 days of the study, soil samples were air-dried and analysed for chemical properties following the aforementioned procedures.

### 2.4 Data Analysis

Analysis of variance (ANOVA) was used to identify the treatment effects, and Tukey's HSD test was used to differentiate the treatment means at  $p \leq 0.05$ . This statistical analysis was performed using the Statistical Analysis System (SAS) On Demand for Academics (Version 9.4).

## 3. RESULTS AND DISCUSSION

### 3.1 Selected chemical properties of soil and organic soil conditioner

#### 3.1.1 Initial selected chemical properties of soil

The soil collected from UNISSA, Sinaut Campus, was analysed for selected chemical properties (Table 1). pH of the soil was measured using both water and 1M KCl solution. The pH value of the soil in water was higher compared with the pH of the soil in KCl, and these differences were due to the solutions used during the analysis. pH in KCl is lower than the pH in water because KCl measures acidity in the soil solution and acidity bound to the soil's colloids, whereas water measures the acidity in the soil solution only (Sadovski, 2019; Wang et al., 2019). The pH values suggest that the soil is strongly acidic, which also aligns with the results of a research conducted in Brunei (USDA NRCS; Grealish and Fitzpatrick, 2013). A study also describes Brunei's soil as strongly acidic and prone to metal toxicity (Zin et al., 2017). One of the causes of a decrease in pH value of the soil is when  $\text{Al}^{3+}$  is adsorbed onto soil exchange complexes, where it undergoes hydrolysis to produce additional  $\text{H}^+$ . The released  $\text{H}^+$  replaces adsorbed base cations, thereby increasing soil acidity (Osman, 2018a). The presence of Fe ions also causes a decrease in pH through the oxidation of  $\text{Fe}^{2+}$  to  $\text{Fe}^{3+}$ , resulting in the release of two protons into the soil solution. As a result, the soil's condition was high in exchangeable acidity and exchangeable  $\text{H}^+$  with a relatively low exchangeable  $\text{Al}^{3+}$ , due to complexation and/or limited solubility, classifying this soil as strongly acidic (low pH), which causes negative effect on agricultural production (Abreu Jr. et al., 2003). The available P concentration of the analysed soil was low (2.63 ppm), reflecting strong fixation under acidic conditions. Even if exchangeable  $\text{Al}^{3+}$  is low, Al- and Fe-oxides in acid soils strongly adsorb phosphate ions, forming insoluble compounds such as aluminium phosphate and/or iron phosphates, which fix P and reduce P availability to plants (Johan et al., 2021; Ch'ng et al., 2017). According to the Unit Sains Tanah dan Nutrien Tanaman, Jabatan Pertanian dan Agri-makanan, Brunei (Soil Science and Nutrient Unit, Department of Agriculture and Agrifood, Brunei), the available P in the soil is below the range required for optimal crop growth.

The soil also showed an EC of  $0.0088 \text{ mS cm}^{-1}$ , classifying the soil as a non-saline soil (Chong et al., 2022). It also indicates a depletion of basic cations, partly because of leaching and weathering of the soil. Heavy rainfall and leaching remove exchangeable base cations ( $\text{K}^+$ ,  $\text{Mg}^{2+}$ ,  $\text{Ca}^{2+}$ ,  $\text{Na}^+$ ) from the soil profile (Warke and Waggari, 2024). As these cations are removed, the concentration of dissolved salts in the soil decreases, directly lowering the EC. When soil pH decreases, silicate minerals begin to dissolve, releasing  $\text{Ca}^{2+}$ ,  $\text{Mg}^{2+}$ , and silica into the soil solution (Rieder et al., 2024). Under these acidic conditions, the released  $\text{Al}^{3+}$  becomes highly mobile and hydrolyses to form Al-hydroxides, which precipitate as Al- or Fe-oxides when Fe is present. However, the released base cations are rapidly adsorbed onto Al-

and Fe-oxides, preventing their accumulation in solution. As a result, even with active mineral weathering, the soil retains low EC because most released basic cations are leached or immobilised instead of remaining in the soil solution. Because of the combination of weathering, heavy rainfall, and leaching, the soil has become low in nutrient content (Table 1). Loss and immobilisation of available nutrients limit soil fertility. A similar finding also reported comparable trends of base cations and emphasized the need for appropriate soil management practices to improve soil productivity (Ng et al., 2022).

The total organic carbon (TOC) and organic matter (OM) which were 1.64% and 2.82%, respectively were relatively low. According to the study, soils with such low TOC and OM levels are generally characterized by poor fertility (Sulok et al., 2021). Similarly, noted that low soil organic carbon and organic matter reduce soil fertility, structure, and biological activity (Abbas et al., 2024). When OM is limited, the soil retains less water and nutrients, has a smaller microbial biomass, and chemically, it results in lower cation-exchange capacity and decreased pH buffering capacity. These degradations reduced crop productivity and overall soil health.

**Table 1:** Selected initial chemical properties of the soil used in the laboratory incubation study

Parameters	Values obtained $\pm$ SE
pH in water	5.11 $\pm$ 0.04
pH in KCl	3.57 $\pm$ 0.006
Electrical conductivity (mS cm <sup>-1</sup> )	0.0088 $\pm$ 0.0001
Exchangeable Acidity (cmol kg <sup>-1</sup> )	0.60 $\pm$ 0.009
Exchangeable Al <sup>+</sup> (cmol kg <sup>-1</sup> )	0.06 $\pm$ 0.003
Exchangeable H <sup>+</sup> (cmol kg <sup>-1</sup> )	0.54 $\pm$ 0.006
Total organic carbon (%)	1.64 $\pm$ 0.03
Organic matter (%)	2.82 $\pm$ 0.06
Available P (ppm)	2.63 $\pm$ 0.05
Available K <sup>+</sup> (ppm)	64.53 $\pm$ 1.56
Exchangeable Ca <sup>2+</sup> (ppm)	3.50 $\pm$ 0.39
Exchangeable Mg <sup>2+</sup> (ppm)	58.2 $\pm$ 2.51
Exchangeable Na <sup>+</sup> (ppm)	34.88 $\pm$ 3.90

### 3.1.2 Selected chemical properties of organic soil conditioner

The organic soil conditioner (OSC) went through the three typical stages of co-composting, which were the mesophilic, thermophilic, and cooling stages. By the end of this process, the OSC becomes stable, mature, and rich in humic substances, marking the completion of the composting process. The OSC produced from the chicken was analysed for its selected physical

and chemical properties, and the results indicate it is of good quality (Table 2). The colour of OSC is described as 10YR 2/1, which corresponds to black on the Munsell colour chart, suggesting that it is rich in carbon and organic matter (Omar et al., 2021; Latifah et al., 2015; Antil et al., 2014; Ch'ng et al., 2013). The high pH indicates that the OSC is neutral and has a liming effect on the soil based on the EC and total nutrients available.

**Table 2:** Selected physical and chemical properties of the organic soil conditioner produced from chicken dung

Parameters	Organic Amendment $\pm$ SE
Colour	10YR 2/1 = Black
pH in water	7.19 $\pm$ 0.05
Electrical conductivity (mS cm <sup>-1</sup> )	8.99 $\pm$ 0.067
Total organic carbon (%)	34.24 $\pm$ 0.44
Organic matter (%)	59.02 $\pm$ 0.76
Total N (%)	4.29 $\pm$ 0.055
Total P (ppm)	8701.43 $\pm$ 184.14
Total K (ppm)	59987.50 $\pm$ 764.13
Total Mg (ppm)	2708.00 $\pm$ 0.58
Total Ca (ppm)	78708.33 $\pm$ 441

### 3.2 Organic Soil Conditioner on Soil pH, Exchangeable Acidity, Exchangeable Aluminium, and Exchangeable Hydrogen

The overall soil pH and EC increased with the application of organic amendment, regardless of the rate applied, indicating a consistent ameliorative effect on soil acidity. The soils with the OSC showed higher pH values in both water and KCl extractions compared with soil only (T1). The soil treated with different amounts of organic amendment also increased soil EC compared with the soil only (T1). The soil EC decreased as the treatment was reduced from 100% to 75%, 50%, and 25%,

consistent with a decline in soluble base cations and nutrient concentration at lower amendment levels.

This increase in pH can be attributed to rapid proton exchange between the acid soil solution and the basic constituents of the organic amendment (Ch'ng et al., 2016; 2014). As decomposition progressed, the release of organic anions further enhanced proton (H<sup>+</sup>) consumption. It promoted the dissolution of base cations such as K, Ca, Mg, and Na, thus contributing to the increase in the soil pH and EC (Ch'ng et al., 2016). Basic nature of the OSC also facilitated neutralization reactions, in which hydroxyl ions

(OH<sup>-</sup>) derived from the dissolution of basic oxides (For example, MgO, K<sub>2</sub>O,

CaO, and NaOH) reacted with H<sup>+</sup> ions in the soil solution from water, thereby reducing acidity (Johan et al., 2021).

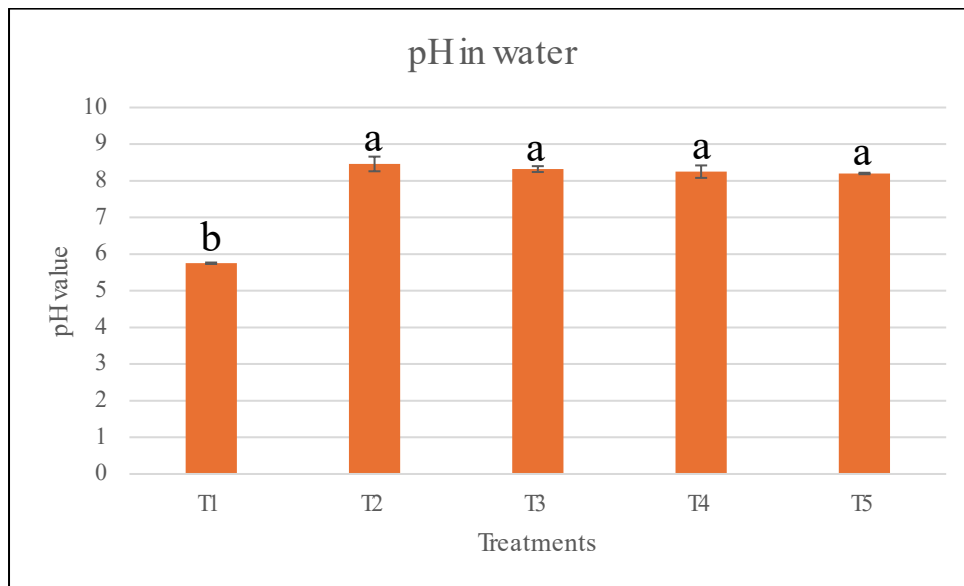


Figure 1: Effect of different amounts of organic soil conditioner on the pH of water

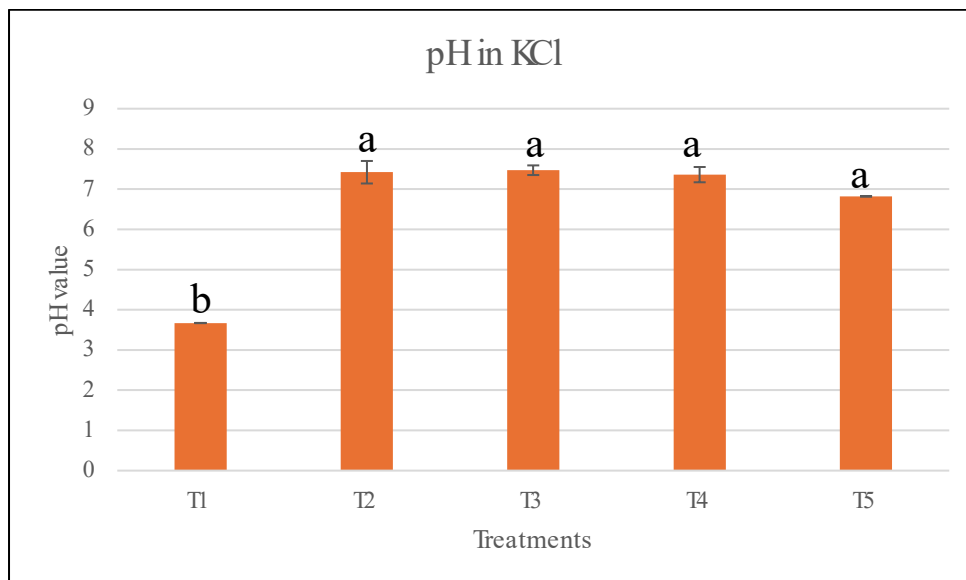


Figure 2: Effect of different amounts of organic soil conditioner on soil pH in KCl

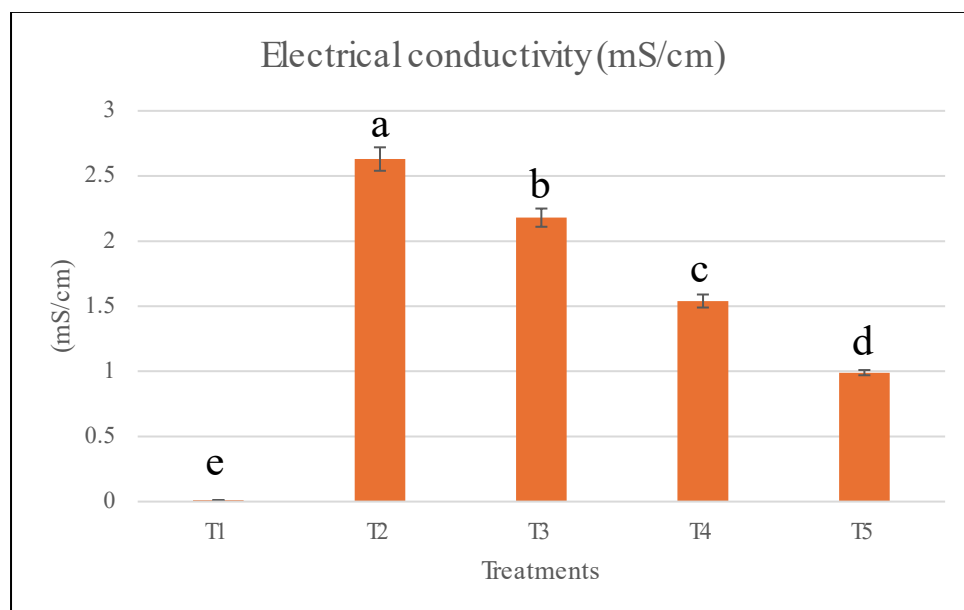


Figure 3: Effect of different amounts of organic soil conditioner on soil electrical conductivity

A concurrent reduction in exchangeable acidity,  $Al^{3+}$ , and hydrogen ( $H^+$ ) was observed in the amended soils. This trend is consistent with previous findings that the decline in exchangeable  $Al^{3+}$  and  $H^+$  is closely related to the increase in soil pH, reflecting a negative correlation between these (Ch'ng et al., 2016; Ch'ng et al., 2014). As soil pH increases, exchangeable and soluble Al ions are transformed into insoluble aluminium hydroxides, thereby reducing their availability in the soil solution (Hamidi et al., 2021;

Ch'ng et al., 2016). Furthermore, the OSC chelated soluble Fe and Al ions through their functional groups which prevent hydrolysis of  $Al^{3+}$  that would otherwise cause release of additional  $H^+$  ions to increase acidity (Hamidi et al., 2021). According to the study, the higher the rate of soil amendment applied, the more pronounced the neutralization effect, as the released base cations displaced  $H^+$  and  $Al^{3+}$  from the cation exchange sites (Johan et al., 2021).

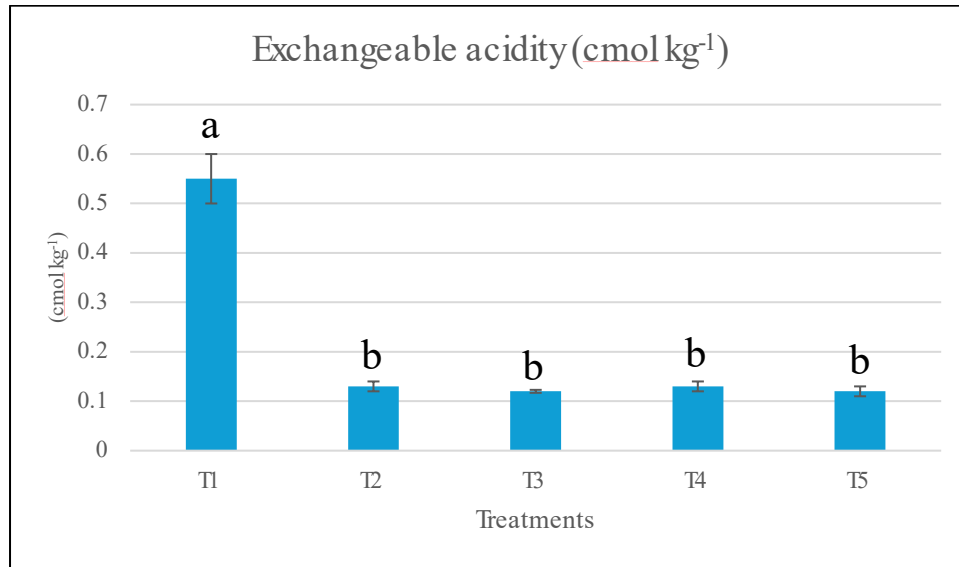


Figure 4: Different amounts of organic soil conditioner on soil exchangeable soil acidity

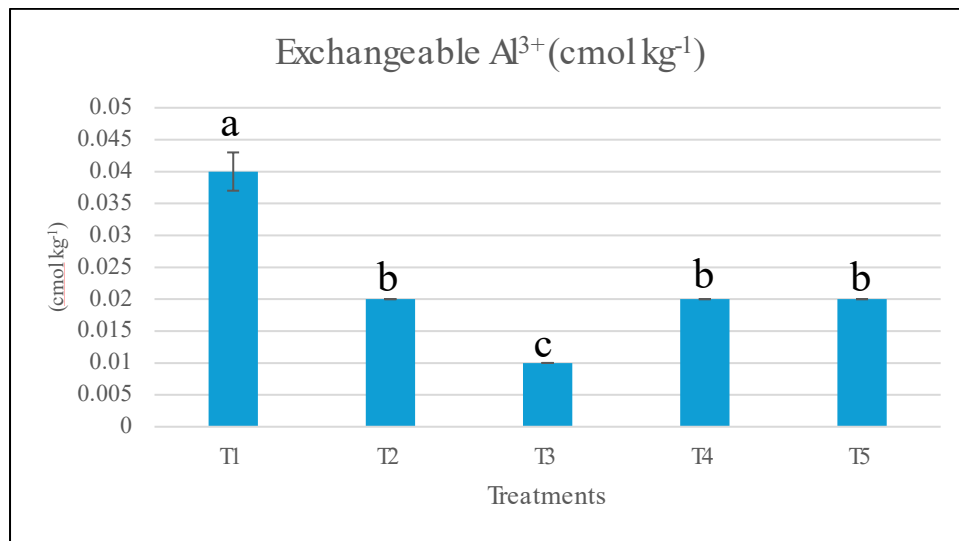


Figure 5: Different amounts of organic soil conditioner on soil exchangeable aluminium ions

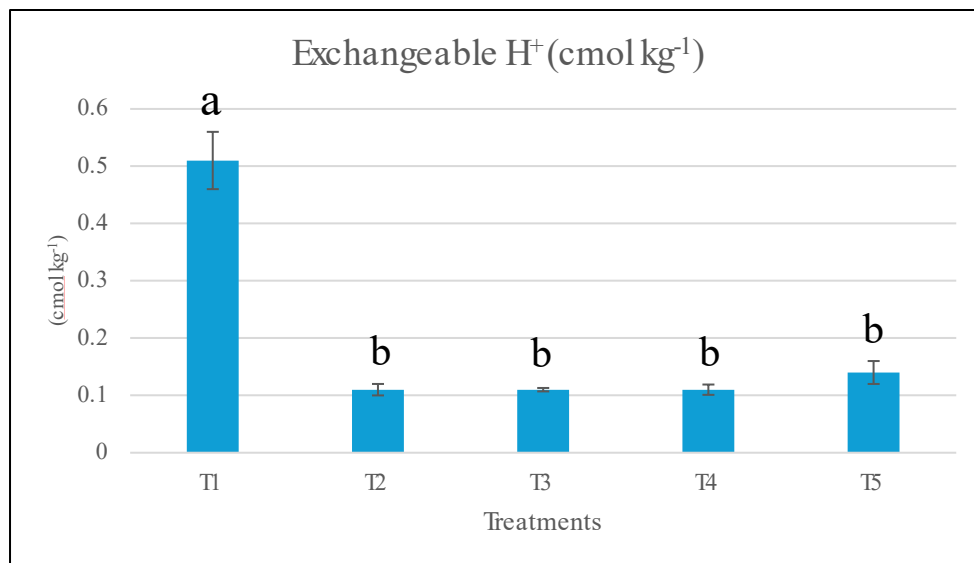


Figure 6: Different amounts of organic soil conditioner on soil exchangeable hydrogen ions

### 3.3 Organic Soil Conditioner on Soil Total Organic Carbon and Organic Matter

Overall, total organic carbon (TOC) and organic matter (OM) increased in the soil with the OSC compared with soil only (T1). The trend observed for the TOC and OM was in the order of T2>T3>T4>T5>T1. The soil only (T1) recorded the lowest TOC (1.24%) and OM (2.14%). The soil with the highest amount of OSC had the highest TOC (7.97%) and OM (13.23%), demonstrating the positive effect of OSC on soil carbon. These results indicate that the higher rates of the OSC resulted in greater accumulation of TOC and OM in the soil.

Improvement in the soil TOC and OM can be attributed to the addition of carbon-rich organic materials, which enhanced soil carbon through both direct input and stimulation of biological activity. According to the study, as organic matter decomposes, nutrients are gradually released thus causing improvement in nutrient retention and enhancing soil microbial processes (Agbede, 2025). This decomposition contributes to higher organic carbon levels by facilitating nutrient transformation and increasing microbial biomass. Similarly, reported that organic

amendments increased soil pH such that it promotes microbial decomposition, resulting in higher total organic carbon (Zaidun et al., 2019). Also found that long-term use of organic amendment increased soil organic carbon by 29.6% to 119.8%, with increases in labile carbon fractions, such as microbial biomass C and particulate organic C, reflecting enhanced microbial activity and macro-aggregate formation (Li et al., 2023). The increase in TOC at higher rates of OSC is related to both labile carbon fractions that promote microbial activity and stable carbon compounds that resist decomposition, leading to sustained organic matter accumulation (Sae-Tun et al., 2024; Li et al., 2023). Likewise, combining organic amendment with fertilizer significantly increased SOC content in aggregates of all particle sizes because addition of foreign carbon improves soil properties, enhanced microbial activity, and facilitated carbon sequestration (Qiang et al., 2024). Sae-Tun et al. (2024) further demonstrated that amendments rich in carbon improved soil organic carbon through increased dissolved organic C, root and microbial growth, and enhanced aggregate stability. These findings support the present results, suggesting that organic amendments improve soil organic carbon and organic matter through nutrient enrichment, microbial stimulation, and the stabilisation of carbon within soil aggregates.

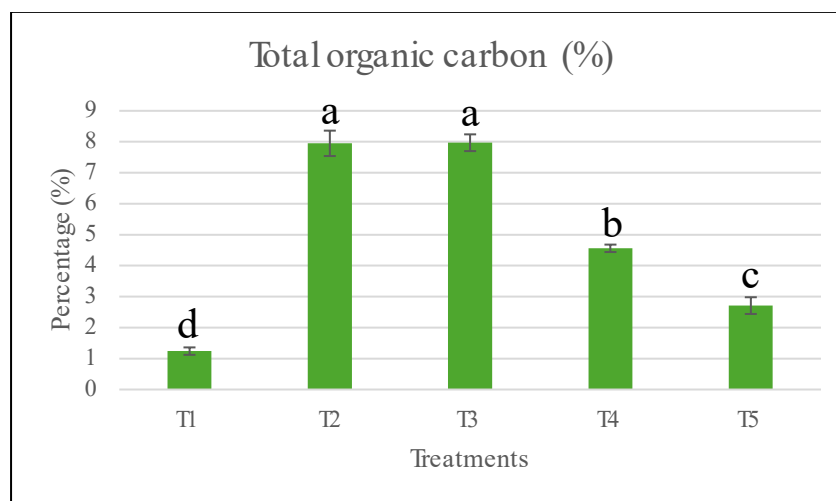


Figure 7: Different amounts of organic soil conditioner on soil total organic carbon

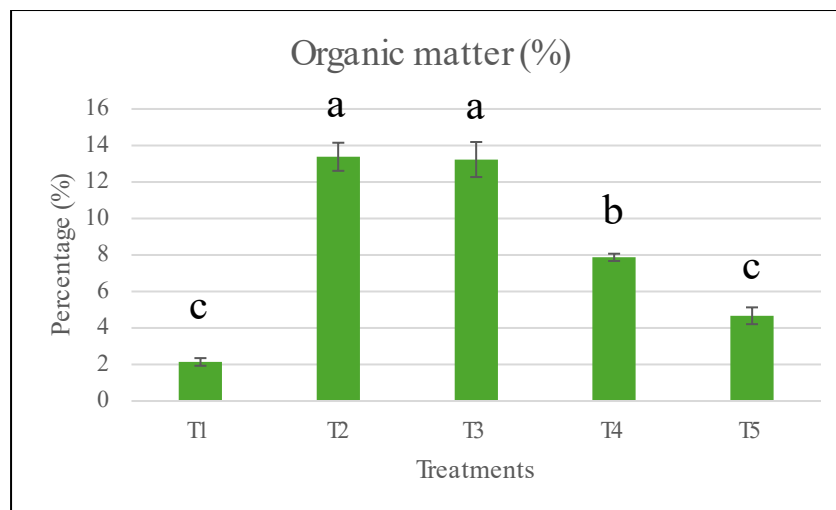


Figure 8: Different amounts of organic soil conditioner on soil organic matter

### 3.4 Organic Soil Conditioner on Soil Available Phosphorus

As for available P, it increased in all amended soils except T1, which indicates that the OSC improves P solubility and availability. Treatments T2 and T3 recorded the highest available P, and a gradual decline can be observed from T2 to T5, suggesting that as the rate of the SOC decreases, available P reduces (Figure 9). The trend between total P and available P differs because not all soil total P was converted to the available form.

Phosphorus is most available to plants when soil pH is near neutral (~6 to 7). In acid soil conditions, phosphate ions readily form insoluble compounds with Al and Fe-oxides, and this reaction limits their availability. Studies have demonstrated that increasing soil pH can counteract this effect by transforming exchangeable Al into less reactive hydroxide forms and mobilizing P from Fe- and Al-bound sites (Chong et al., 2022; Toluwase Oreoluwa et al., 2020). As suggest an increase in soil

pH releases fixed P into soil solution, either through dissolution or desorption (Johan et al., 2021). An increase in pH caused by organic amendments also enhances microbial decomposition, promoting the conversion of organic P to its inorganic forms.

Higher levels of organic carbon and organic matter further support P availability by improving nutrient cycling and reducing fixation. Organic inputs, such as organic amendments, supply additional P sources and stimulate microbial activity by providing energy for microbes besides forming organic complexes with Al and Fe that prevent P precipitation (Toluwase Oreoluwa et al., 2020; Ch'ng et al., 2016). The low C/P ratio of compost and biochar favours mineralization, leading to a higher concentration of plant-available P (Ch'ng et al., 2016). According to the study, both acid and neutral phosphate activities strongly correlate with available P, indicating that enzyme-mediated mineralization plays an

important role in converting organic P into inorganic forms (Shi et al., 2024). They reported that organic amendments enhanced this process by improving microbial habitats and stimulating phosphate-solubilizing microorganisms.

Microbial activity is a key driver of these processes because it regulates the balance between mineralization and immobilization of P. Soils enriched with organic amendments tend to provide higher microbial

biomass and phosphatase activity, leading to a greater release of plant-available P (Chong et al., 2022; Ch'ng et al., 2016). Further demonstrated that combining biochar and ash does not only improve soil pH and CEC but it also enhances microbial functioning, resulting in significantly higher P and N availability (Asirifi et al., 2025). Overall, maintaining higher pH and organic matter content using organic amendments is crucial for minimizing P fixation and promoting microbial activities in acid soils.

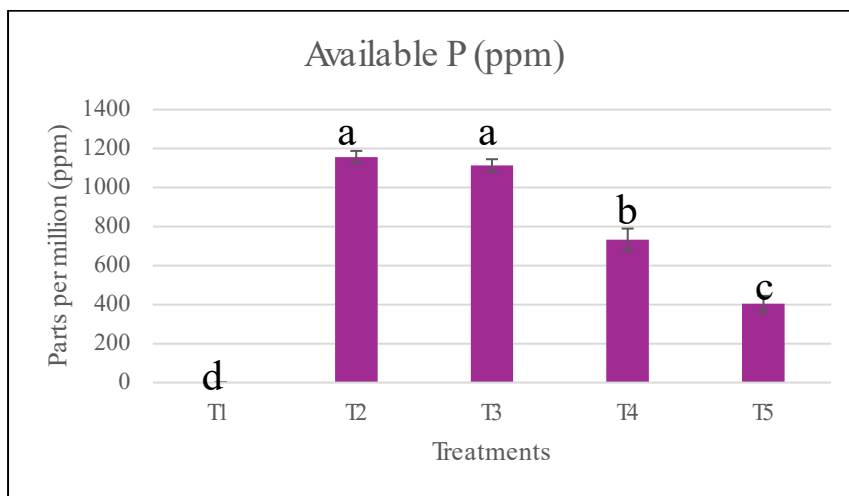


Figure 9: Different amounts of organic soil conditioner on soil available phosphorus

### 3.5 Organic Soil Conditioner on Soil Available Potassium, and Exchangeable Calcium, Magnesium, and Sodium

The soil exchangeable K, Ca, Mg, and Na are presented in Figure 10. The soils with T2 had the highest concentration of exchangeable K, Ca, Mg, and Na followed by T3 to T5 and T1. However, for exchangeable Ca, T4 had the second-highest accumulation of exchangeable Ca, followed by T3, T5, and the lowest accumulation of Ca occurred with T1. The results indicate that application of the OSC improves soil exchangeable base cations, which are important for plant growth.

Organic amendment enhances the availability of base cations in soils mainly by increasing soil organic matter (SOM), which raises the soil's CEC through negatively charged functional groups such as carboxyl and phenolic groups that adsorb and exchange  $Ca^{2+}$ ,  $Mg^{2+}$ , and  $K^+$ , improving their retention and reducing leaching. As reported that compost-amended soils retained  $NH_4^+$ ,  $K^+$ ,  $Ca^{2+}$ ,  $Mg^{2+}$ , and  $Na^+$  because of the higher negative charges of humic and fulvic acids of compost characterised by enhanced nutrient availability and maize biomass resulting from the combined use

of compost, zeolite, and fertilizer (Latifah et al., 2017). Organic amendments also directly supply nutrients as they decompose, releasing exchangeable base cations and organic acids that improve soil structure and nutrient mobility (Nurdianto et al., 2024). As found that organic amendments such as biochar and compost contribute K, Ca, and Mg through their ash and liming effects, improving pH and nutrient availability, whereas noted that the use of biochar and chicken dung as soil conditioners retains nutrients through adsorption and co-precipitation, and its porous structure supports microbial activity, promoting nutrient mineralization (Sulok et al., 2021; Abbas et al., 2024). Supporting these findings, demonstrated that increased SOM improves CEC because of negatively charged functional groups, such as carboxyl (-COOH) and hydroxyl (-OH), which enhance the soil's ability to retain base cations (Yang et al., 2024). This increase in CEC improved balance of exchangeable cations, enhancing K and Mg uptake, N content, chlorophyll levels, and dry biomass in seedlings, reducing the negative impact of nutrient imbalance. These processes enhance soil CEC, aeration, and microbial function, resulting in greater retention and availability of base cations and improved soil fertility.

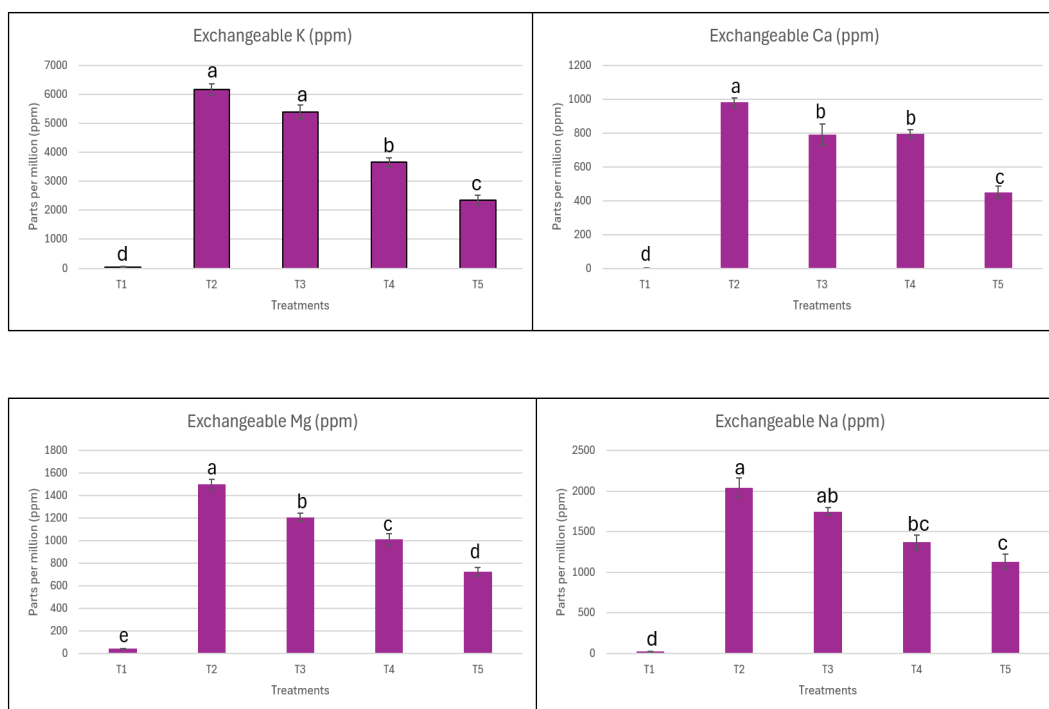


Figure 10: Different amounts of organic soil conditioner on soil available potassium, and exchangeable calcium, magnesium, and sodium

#### 4. CONCLUSION

The OSC produced from chicken dung effectively increases soil pH, EC, TOC, OM, and yet it reduces exchangeable acidity, aluminium, and hydrogen ions. These improvements were accompanied by enhanced nutrient availability, especially P and base cations, aligning with the organic amendment's liming effect, enrichment of soil organic carbon, and stimulation of microbial activity. Higher rate of the OSC (T2 and T3) produced the most noticeable effect, indicating a direct relationship between OSC application and soil fertility improvement.

Overall, the results highlight that organic amendments play a vital role in ameliorating soil acidity, improving nutrient retention including P, and enhancing overall soil fertility of the acid soil. Its incorporation into soil management practices can promote sustainable crop production by restoring soil health, reducing nutrient losses, and supporting long-term agricultural productivity.

#### ACKNOWLEDGEMENT

The authors would like to thank the Universiti of Sultan Sharif Ali for funding this research under the Research Grant (CRP0012-2022): *Organic Approach for Restoring Phosphorus Availability to Improve Acid Soil and Crop Productivity in Brunei Darussalam* and the technical assistance provided by the Ibnu Sina Scientific Laboratory Centre, UNISSA, Brunei, and Unit of Soil Science and Plant Nutrient, Department of Agriculture and Agrifood, Brunei for the laboratory analysis.

#### REFERENCES

Abbas, A., Naveed, M., Shehzad Khan, K., Ashraf, M., Siddiqui, M. H., Abbas, N., Mustafa, A., and Ali, L., 2024. The Efficacy of Organic Amendments on Maize Productivity, Soil Properties and Active Fractions of Soil Carbon in Organic-Matter Deficient Soil. *Spanish Journal of Soil Science*, 14(June), Pp. 1–14. <https://doi.org/10.3389/sjss.2024.12814>

Abreu Jr., C. H., Muraoka, T., and Lavorante, A. F., 2003. Relationship between acidity and chemical properties of brazilian soils. *Scientia Agricola*, 60(2), Pp. 337–343. <https://doi.org/10.1590/S0103-90162003000200019>

Agbede, T. M., 2025. Poultry manure improves soil properties and grain mineral composition, maize productivity and economic profitability. *Scientific Reports*, 15(1), 16501. <https://doi.org/10.1038/s41598-025-00394-8>

Antil, R. S., Raj, D., Abdalla, N., and Inubushi, K., 2014. Physical, Chemical and Biological Parameters for Compost Maturity Assessment: A Review. In D. K. Maheshwari (Ed.), *Composting for Sustainable Agriculture* (pp. 83–101). Spring, Cham. [https://doi.org/10.1007/978-3-319-08004-8\\_5](https://doi.org/10.1007/978-3-319-08004-8_5)

Asirifi, I., Makarowsky, L., Heinze, S., Herre, M., Werner, S., Frimpong, K. A., Pierburg, R., and Marschner, B., 2025. Biochar and Kitchen Stove Ash for Improving Nutrient Availability and Microbial Functions of Tropical Acidic Soil. *Soil Systems*, 9(2), Pp. 1–17. <https://doi.org/10.3390/soilsystems9020049>

Ch'ng, H. Y., Ahmed, O. H., and Majid, N. M. A., 2014. Improving Phosphorus Availability in an Acid Soil Using Organic Amendments Produced from Agroindustrial Wastes. *The Scientific World Journal*, 2014, Pp. 1–6. <https://doi.org/10.1155/2014/506356>

Ch'ng, H. Y., Ahmed, O. H., and Majid, N. M. A., 2016. Improving Phosphorus Availability, Nutrient Uptake and Dry Matter Production of Zea Mays L. on a Tropical Acid Soil Using Poultry Manure Biochar and Pineapple Leaves Compost. *Experimental Agriculture*, 52(3), Pp. 447–465. <https://doi.org/10.1017/S0014479715000204>

Ch'ng, H. Y., Ahmed, O. H., and Nik, N. M., 2014. Biochar and compost influence the phosphorus availability, nutrients uptake, and growth of maize (*Zea mays* L.) in tropical acid soil. *Pakistan Journal of Agricultural Sciences*, 51(4), Pp. 797–806.

Ch'ng, H. Y., Ahmed, O. H., Kassim, S., and Majid, N. M. A., 2013. Co-composting of pineapple leaves and chicken manure slurry. *International Journal Of Recycling of Organic Waste in Agriculture*, 2(1), Pp. 23. <https://doi.org/10.1186/2251-7715-2-23>

Ch'ng, H. Y., Ahmed, O. H., Majid, N. M. A., and Jalloh, M. B., 2017. Reducing Soil Phosphorus Fixation to Improve Yield of Maize on a Tropical Acid Soil Using Compost and Biochar Derived from Agro-Industrial Wastes. *Compost Science and Utilization*, 25(2), Pp. 82–94. <https://doi.org/10.1080/1065657X.2016.1202795>

Chen, J., Yu, J., Li, Z., Zhou, J., and Zhan, L., 2023. Ameliorating Effects of Biochar, Sheep Manure and Chicken Manure on Acidified Purple Soil. *Agronomy*, 13(4). <https://doi.org/10.3390/agronomy13041142>

Chong, I. Q., Azman, E. A., Ng, J. F., Ismail, R., Awang, A., Hasbullah, N. A., Murdad, R., Ahmed, O. H., Musah, A. A., Alam, M. A., Besar, N. A., Tajidin, N. E., and Jalloh, M. B., 2022. Improving Selected Chemical Properties of a Paddy Soil in Sabah Amended with Calcium Silicate: A Laboratory Incubation Study. *Sustainability*, 14(20), 13214. <https://doi.org/10.3390/su142013214>

Dikinya, O., and Mufwanzala, N., 2010. Chicken manure-enhanced soil fertility and productivity: Effects of application rates. *Journal of Soil Science and Environmental Management*, 1(3), Pp. 46–54. <http://www.academicjournals.org/JSSEM>

Dvořáčková, H., Dvořáček, J., González, P. H., and Vlček, V., 2022. Effect of different soil amendments on soil buffering capacity. *PLoS ONE*, 17(2 February), Pp. 1–16. <https://doi.org/10.1371/journal.pone.0263456>

FAO, and ITPS., 2015. Status of the World's Soil Resources (SWSR) – Main Report. <https://hal.archives-ouvertes.fr/hal-01241064/>

FAO., 2021a. Standard operating Procedure for soil available phosphorus - Mehlich I method.

FAO., 2021b. Standard operating procedure for soil electrical conductivity, soil/water, 1: 5.

FAO., 2021c. Standard operating procedure for soil pH determination.

Global Soil Laboratory Network, and Nilo, G., 2019. Standard operating procedure for soil organic carbon Walkley-Black method: Titration and colorimetric method. In *Food and Agriculture Organization of the United Nations* (Vol. 1, Issue 20).

Grealish, G. J., and Fitzpatrick, R. W., 2013. Acid sulphate soil characterization in Negara Brunei Darussalam: a case study to inform management decisions. *Soil Use and Management*, 29(3), Pp. 432–444. <https://doi.org/10.1111/sum.12051>

Hamidi, N. H., Ahmed, O. H., Omar, L., and Ch'ng, H. Y., 2021. Combined use of charcoal, sago bark ash, and urea mitigate soil acidity and aluminium toxicity. *Agronomy*, 11(9). <https://doi.org/10.3390/agronomy11091799>

Islam, M. R., Jahan, R., Uddin, S., Harine, I. J., Hoque, M. A., Hassan, S., Hassan, M. M., and Hossain, M. A., 2021. Lime and Organic Manure Amendment Enhances Crop Productivity of Wheat–Mungbean–T. Aman Cropping Pattern in Acidic Piedmont Soils. *Agronomy*, 11(8), Pp. 1595. <https://doi.org/10.3390/agronomy11081595>

Johan, P. D., Ahmed, O. H., Maru, A., Omar, L., and Hasbullah, N. A., 2021. Optimisation of Charcoal and Sago (Metroxylon sago) Bark Ash to Improve Phosphorus Availability in Acidic Soils. *Agronomy*, 11(9), 1803. <https://doi.org/10.3390/agronomy11091803>

Johan, P. D., Ahmed, O. H., Omar, L., and Hasbullah, N. A., 2021. Charcoal and Sago Bark Ash on pH Buffering Capacity and Phosphorus Leaching. *Agronomy*, 11(11), 2223. <https://doi.org/10.3390/agronomy11112223>

Latifah, O., Ahmed, O. H., and Majid, N. M. A., 2017. Short Term Enhancement of Nutrients Availability in Zea mays L. Cultivation on an Acid Soil Using Compost and Clinoptilolite Zeolite. *Compost Science and Utilization*, 25(1), Pp. 22–35. <https://doi.org/10.1080/1065657X.2016.1172054>

Latifah, O., Ahmed, O. H., Susilawati, K., and Majid, N. M., 2015. Compost maturity and nitrogen availability by co-composting of paddy husk and chicken manure amended with clinoptilolite zeolite. *Waste Management and Research: The Journal for a Sustainable Circular Economy*, 33(4), Pp. 322–331. <https://doi.org/10.1177/0734242X15576771>

Li, S., Wei, W., and Liu, S., 2023. Long-Term Organic Amendments Combined with Nitrogen Fertilization Regulates Soil Organic Carbon Sequestration in Calcareous Soil. *Agronomy*, 13(2), Pp. 291. <https://doi.org/10.3390/agronomy13020291>

Maikol, N., Haruna, A. O., Maru, A., Asap, A., and Medin, S., 2021. Utilization of urea and chicken litter biochar to improve rice production. *Scientific Reports*, 11(1), 9955. <https://doi.org/10.1038/s41598-021-89332-y>

Malhotra, H., Vandana, Sharma, S., and Pandey, R., 2018. Phosphorus Nutrition: Plant Growth in Response to Deficiency and Excess. In M. Hasanuzzaman, M. Fujita, H. Oku, K. Nahar, and B. Hawrylak-Nowak

- (Eds.), *Plant Nutrients and Abiotic Stress Tolerance* (pp. 171–190). Springer Singapore. [https://doi.org/10.1007/978-981-10-9044-8\\_7](https://doi.org/10.1007/978-981-10-9044-8_7)
- Moursy, A. R., Ahmed, N., and Sahoo, R., 2020. Determination of total content of some microelements in soil using two digestion methods. *International Journal of Chemical Studies*, 8(2), Pp. 2510–2514. <https://doi.org/10.22271/chemi.2020.v8i2a1.9127>
- Murphy, J., and Riley, J. P., 1962. A modified single solution method for the determination of phosphate in natural waters. *Analytica Chimica Acta*, 27(C), Pp. 31–36. [https://doi.org/10.1016/S0003-2670\(00\)88444-5](https://doi.org/10.1016/S0003-2670(00)88444-5)
- Ng, J. F., Ahmed, O. H., Jalloh, M. B., Omar, L., Kwan, Y. M., Musah, A. A., and Poong, K. H., 2022. Soil Nutrient Retention and pH Buffering Capacity Are Enhanced by Calciprill and Sodium Silicate. *Agronomy*, 12(1), 219. <https://doi.org/10.3390/agronomy12010219>
- Ng, J. F., Ahmed, O. H., Omar, L., Jalloh, M. B., Kwan, Y. M., Musah, A. A., and Chowdhury, A. J. K., 2024. Improving pH buffering capacity of an acid soil to regulate nutrient retention and mitigate water pollution using Calciprill and sodium silicate. *Desalination and Water Treatment*, 319(March), 100491. <https://doi.org/10.1016/j.dwt.2024.100491>
- Nurdianto, R., Hanuf, A. A., Lutfi, M. W., Suntari, R., and Soemarno, S., 2024. Analysis of Soil Base Cations Content after Application of Organic Fertilizer on Inceptisols at Lemon-Tree Orchard. 8(1), Pp. 1–10. <https://doi.org/10.20961/agrotechresj.v8i1.73263>
- Omar, L., Ahmed, O. H., Boyie Jalloh, M., and Abdul Majid, N. M., 2021. Rice Husk Compost Production and Use in Mitigating Ammonia Volatilization from Urea. *Sustainability*, 13(4), 1832. <https://doi.org/10.3390/su13041832>
- Osman, K. T., 2018a. Acid Soils and Acid Sulfate Soils. In *Management of Soil Problems* (pp. 299–332). Springer International Publishing. [https://doi.org/10.1007/978-3-319-75527-4\\_11](https://doi.org/10.1007/978-3-319-75527-4_11)
- Osman, K. T., 2018b. *Management of Soil Problems*. In Springer. Springer International Publishing. <https://doi.org/10.1007/978-3-319-75527-4>
- Qiang, M., Zhang, X., Zhuang, X., and Zhang, H., 2024. Effect of Organic Amendment and Mineral Fertilizer on Soil Aggregate Stability and Maize Yield on the Loess Plateau of China. *Polish Journal of Environmental Studies*, 33(3), Pp. 2255–2265. <https://doi.org/10.15244/pjoes/174782>
- Rieder, L., Amann, T., and Hartmann, J., 2024. Soil electrical conductivity as a proxy for enhanced weathering in soils. *Frontiers in Climate*, 5. <https://doi.org/10.3389/fclim.2023.1283107>
- Rowell, D. L., 1994. *Soil Science: Methods and Applications* (1st ed.). Routledge. <https://doi.org/10.4324/9781315844855>
- Sadovski, A. N., 2019. Study on pH in water and potassium chloride for Bulgarian soils. *EURASIAN JOURNAL OF SOIL SCIENCE (EJSS)*, 8(1), Pp. 11–16. <https://doi.org/10.18393/ejss.477560>
- Sae-Tun, O., Maftukhah, R., Susanto, S., Ngadisih, N., Murtiningrum, M., Hood-Nowotny, R., Mentler, A., Bodner, G., and Keiblinger, K. M., 2024. Organic carbon-based amendments effectively reclaim post-tin mining site via modified soil organic carbon characteristics. *Plant and Soil*, 0123456789. <https://doi.org/10.1007/s11104-024-06833-1>
- Shen, J., Yuan, L., Zhang, J., Li, H., Bai, Z., Chen, X., Zhang, W., and Zhang, F., 2011. Phosphorus Dynamics: From Soil to Plant. *Plant Physiology*, 156(3), Pp. 997–1005. <https://doi.org/10.1104/pp.111.175232>
- Shi, X., Gu, D., Yang, H., Li, Y., Jiang, Y., Zhan, N., and Cui, X., 2024. Effect of Exogenous Organic Matter on Phosphorus Forms in Middle-High Fertility Cinnamon Soil. *Plants*, 13(10), Pp. 1–15. <https://doi.org/10.3390/plants13101313>
- Sulok, K. M. T., Ahmed, O. H., Khew, C. Y., Zehnder, J. A. M., Lai, P. S., Jalloh, M. B., Musah, A. A., Awang, A., and Abdu, A., 2021. Effects of Organic Amendments Produced from Agro-Wastes on Sandy Soil Properties and Black Pepper Morpho-Physiology and Yield. *Agronomy*, 11(9), 1738. <https://doi.org/10.3390/agronomy11091738>
- Thepsilvisut, O., Chutimanukul, P., Sae-Tan, S., and Ehara, H., 2022. Effect of chicken manure and chemical fertilizer on the yield and qualities of white mugwort at dissimilar harvesting times. *PLOS ONE*, 17(4), e0266190. <https://doi.org/10.1371/journal.pone.0266190>
- Toluwase Oreoluwa, A., Tolulope Yetunde, A., Joseph, U. E., Chengsen, Z., and Hongyan, W., 2020. Effect of Biochar and Poultry Litter Application on Chemical Properties and Nutrient Availability of an Acidic Soil. *Communications in Soil Science and Plant Analysis*, 51(12), Pp. 1670–1679. <https://doi.org/10.1080/00103624.2020.1791158>
- USDA NRCS., 1998. Soil quality indicators: pH.
- Wang, A., Li, D., Huang, B., and Lu, Y., 2019. A Brief Study on Using pH<sub>H2O</sub> to Predict pH<sub>KCl</sub> for Acid Soils. *Agricultural Sciences*, 10(02), Pp. 142–149. <https://doi.org/10.4236/as.2019.102012>
- Warke, A., and Wakgari, T., 2024. A Review on the Impact of Soil Acidification on Plant Nutrient Availability, Crop Productivity, and Management Options in the Ethiopian Highlands. *Agriculture, Forestry and Fisheries*, 13(2), Pp. 31–45. <https://doi.org/10.11648/j.aff.20241302.13>
- Weil, R. R., and Brady, N. C., 2016. *The Nature and Properties of Soils*. In Pearson (15th ed.). Pearson Education.
- Yang, M., Zhou, D., Hang, H., Chen, S., Liu, H., Su, J., Lv, H., Jia, H., and Zhao, G., 2024. Effects of Balancing Exchangeable Cations Ca, Mg, and K on the Growth of Tomato Seedlings (*Solanum lycopersicum* L.) Based on Increased Soil Cation Exchange Capacity. *Agronomy*, 14(3). <https://doi.org/10.3390/agronomy14030629>
- Zaidun, S. W., Jalloh, M. B., Awang, A., Sam, L. M., Besar, N. A., Musta, B., Ahmed, O. H., and Omar, L., 2019. Biochar and clinoptilolite zeolite on selected chemical properties of soil cultivated with maize (*Zea mays* L.). *EURASIAN JOURNAL OF SOIL SCIENCE (EJSS)*, 8(1), Pp. 1–10. <https://doi.org/10.18393/ejss.468100>
- Zin, K. P., Lim, L. H., Bandara, J. M. R. S., and Thippeswamy, H. M., 2017. Heavy Metals in Paddy Soils of Brunei Darussalam and Their Relationship with Selected Soil Properties. *International Journal of Environmental Monitoring and Analysis*, 5(3), 64. <https://doi.org/10.11648/j.ijema.20170503.11>

